High permittivity solid ceramic resonators for high field human MRI

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Target Audience MRI coil designers, researchers working in high field musculoskeletal MRI.

Purpose To investigate the properties of high permittivity low-loss ceramics as efficient resonators for high field MRI. In vivo applications are aimed towards imaging individual digits while providing a high filling factor and patient comfort.

Introduction The vast majority of radiofrequency (RF) coils for MRI are constructed from electrically conductive elements, usually copper or silver-coated copper. A potential alternative is to use high permittivity, low-loss ceramic materials [1]. In this work, a dielectric resonator made from barium strontium titanate, has been designed to operate in degenerate quadrature $HEM_{11\delta}$ modes at 298.1 MHz (7 Tesla). The resonator was designed for high resolution imaging of human digits. New designs for double-tuned resonator configurations are also introduced.

Methods An annular ceramic cylinder with a height of 6.3 cm and an outer diameter of 8.6 cm, dielectric constant ~178, loss tangent <0.01, was designed and a central hole with a diameter of 2.5 cm was produced using ultrasonic milling. Two inductively-coupled loops with a diameter of 30 mm were spaced 90 degrees apart to excite the quadrature $HEM_{11\delta}$ modes of the resonator, and critically coupled to match to 50Ω. A copper shield was mounted concentric to the ceramic cylinder: Figure A shows the assembled resonator. The S_{11} of each channel was less then -20 dB when loaded with a human digit and the S_{21} between the channels was also less than -20 dB. B_1^+ maps were obtained using the method of Yarnykh [2]. For in vivo imaging a 3D gradient echo sequence was run: TE/TR 10 ms/5 ms, tip angle 10°, field-of-view 50 x 100 x 25 mm, data acquisition matrix 332 x 340 x 50 (zero-filled to 800 x 800 x 50 for image display), spatial resolution 0.15 x 0.3 x 0.5 mm, total image acquisition time 86 seconds.

Results Figures (B) and (C) show the high degree of homogeneity throughout the centre of the sample associated with the quadrature HEM mode, with a maximum value of 6.5 µT/√W. Figure D shows two adjacent slices from the high resolution 3D gradient set, with excellent delineation of the very thin cartilage layer between joints, as well as the fine structure of the trabecular bone. In E, two new schemes of double-tuning, without requiring the conventional lumped-element trap networks, are shown via network analyzer plots.

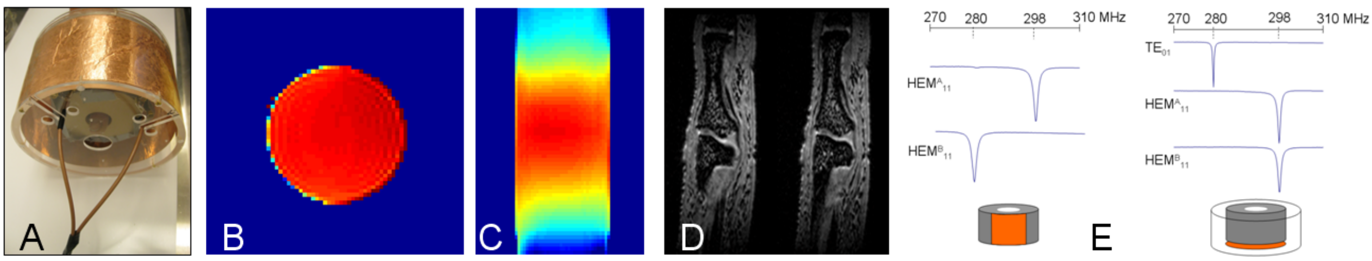

Figure (A) *Photograph of the assembled resonator. (B) and (C) Measured transverse and sagittal B_1^+ maps at the centre of the resonator obtained with a 0.9% saline phantom (radius 12 mm, length 120 mm). (D) Two adjacent high resolution image of a human finger showing fine detail of cartilage and trabecular bone. (E) Two methods of double-tuning the ceramic resonator to proton and fluorine (280 MHz). On the left a 90° coverage shield shifts one of the HEM modes (denoted HEM^A) up to 298 MHz while the other mode (denoted HEM^B) is unaffected. On the right, an additional shield placed below the resonator shifts the TE mode from 251 MHz to 280 MHz while the two orthogonal HEM modes remain at 298 MHz.*

Discussion In contrast to previous high field MRI resonator designs using water as the high permittivity material [3,4], the ceramic resonator presented here does not give a proton signal, has a lower loss factor, and has a more compact design due to its higher permittivity. Fine tuning to different loads is possible using the inductive matching network. The high sensitivity allows very short imaging times for maximum patient comfort. The intrinsic orthogonality of the TE and HEM modes of such a resonator allows simple and robust multi-frequency tuning to be implemented with appropriate positioning of an RF shield.

Conclusion The simplicity and flexibility of low-loss high permittivity ceramics enables efficient and robust resonators to be designed for high field human MRI.

References. [1] Haines K, Neuberger T, Lanagan M, Semouchkina E, Webb AG. J Magn Reson 2009;200:349-353. [2] Yarnykh VL. Magn Reson Med 2007;57:192-200. [3].Wen H, Jaffer FA, Denison TJ, Duewell S, Chesnick AS, Balaban RS. J Magn Reson Ser B 1996;110:117-123.[4] Aussenhofer SA, Webb AG. Magn Reson Med 2012;68:1325-1331.